Comprehensive Study of Printed Antennas on Human Body for Medical Applications

Albert Sabban

Electronic Engineering Department ORT Braude College, Karmiel, Israel, 21982

sabban@netvision.net.il

Abstract

Biomedical industry is in continuous growth in the last few years. Compact antennas are crucial in the development of biomedical systems on human body. The interaction between printed antennas and human body has been investigated in this paper. Antennas electrical performance is altered significantly in vicinity to human body. This paper presents the performance of several printed antennas as a function of the distance from human body. Several new wideband printed antennas that operate in vicinity to human body are also presented in this paper.Tuneable antennas may be used to compensate variations in the antenna resonant frequency at different locations on the human body.If the air spacing between the new antenna and the human body is increased from 0mm to 5mm, the antenna resonant frequency is shifted by 5%.

Keywords

Medical Applications; Wearable Antennas

Introduction

Microstrip antennas, widely employed in communication system and seekers, holds attractive features such as low profile, flexibility, light weight, small volume and low production cost.In addition, the benefit of a compact low cost feed network is attained by integrating the RF frontend with the radiating elements on the same substrate. Several wearable antennas have been presented in papers in the last decade as presented by Alomainy A., Gupta B., and Izdebski P. M. Microstrip antennas are widely presented in books and papers in the last decade as presented byJames J.R., P.S Hall and Sabban A. in 1983. The effect of human body on the electrical performance of wearable antennas at microwave frequencies was not presented byKellomakiand Lawrence C. Chirwa. RF transmission properties of human tissues have been investigated by Lawrence C. Chirwa and Werber D. A review of wearable and body mounted antennas designed and developed for various applications at different frequency bands over the last decade are presented byGupta B. Thalmann T.;

Popovic Z. presented a meander wearable antennas in close proximity of a human body in the frequency range between 800MHz and 2700MHz. Salonen, P. and Rahmat-Samiipresented a textile antenna performance in the vicinity of the human body at 2.4GHz. Numerical results with and without the presence of the human body are discussed in this paper. The effect of human body on a wearable portable radio antennas were studied at 100MHz by Kellomaki T. He concluded that wearable antennas need to be shorter by 15% to 25% from the antenna length in free-space. Measurements of the antenna gain presented by Kellomaki T.shows that a wide dipole (116x10cm) has -13dBi gain. The antennas presented by Gupta B.and Kellomaki T.were developed mostly for cellular applications. Requirements and the frequency range of medical systems are not the same as in cellular industry. A new class of wideband compact wearable microstrip antennas for medical applications is presented in this paper. The antennas VSWR is better than 2:1at 434MHz$\pm$5%. The antenna beam width is around 100º.The antennas gain is around 0 to 4dBi. The antenna resonant frequency is shifted by 5% if the air spacing between theantenna and the human body is increased from,0mm to 5mm.
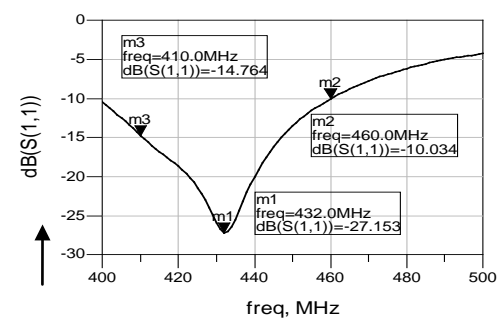
Dual Polarized 434MHz Printed Antenna

A new compact microstrip loaded dipole antennas has been designed to provide horizontal polarization. The antenna dimensions have been optimized to operate on the human body by employing ADS software. The printed slot antenna provides a vertical polarization. In several medical systems, the required polarization may be vertical or horizontal polarization. The proposed antenna is dual polarized. The printed dipole and the slot antenna provide dual orthogonal polarizations. The antenna consists of two layers of which the first layer has RO3035 0.8mm dielectric substrate and thesecond layerisDuroid 5880 0.8mm substrate.The substrate thickness determines the antenna band width. However, thinner antennas are

flexible. Thicker antennas with wider bandwidth have been designed. The dimensions of the dual polarized antenna shown in Fig 1 are 26x6x0.16cm. The antenna, used as a wearable antenna on human body and analysed using Agilent ADS software, may be attached to the patient shirt in the patient stomach or back zone.The matching stubs width and length has been optimized to get the best VSWR results at the antenna input ports. The length of the stub L is 10mm. The number and location of the coupling stubs control the axial ratio value. The axial ratio value may vary from 0dB to 20dB due to different location and number of the coupling stubs. The length and width of the coupling stubs in Fig. 1 are 12mm by 10mm.The number of coupling stubs may be minimized to around four. The antenna cross polarized field strength may be adjusted by varying the slot feed location. There is a good agreement between measured and computed results. The antenna bandwidth is around 10% for VSWR better than 2:1. The antenna beam width is around 100º. The antenna gain is around 2dBi. The computed S11 and S22parameters are presented in Fig. 2. Fig. 3 presents the antenna measured S11 parameters. The computed radiation pattern is shown in Fig. 4. The dimensions of the folded dual polarized antenna presented in Fig. 5 are 7x5x0.16cm. . The length and width of the coupling stubs in Fig. 5 are 9mm to 12mm. Small tuning bars are located along the feed line to tune the antenna to

the desired resonant frequency. Fig. 6 presents the antenna computed S11 and S22 parameters. The computed radiation pattern of the folded dipole is shown in Fig. 7.

The antennas radiation characteristics on human body have been measured by using a phantom. The phantom electrical characteristics represent the human body electrical characteristics. The phantom has a cylindrical shape with a 40cm diameter and a length of 1.5m. The phantom contains a mix of 55% water 44% sugar and 1% salt. The antenna under test was placed on the phantom during the measurements of the antennas radiation characteristics.

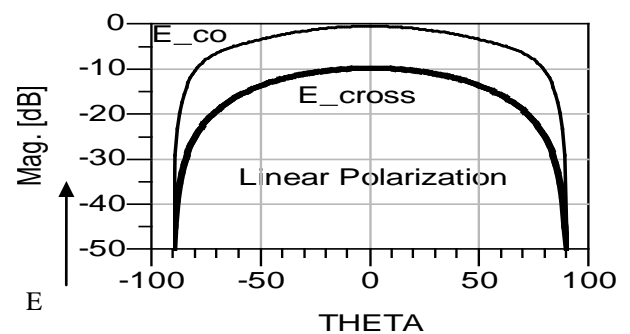FIG. 3: MEASURED S11 ON HUMAN BODY

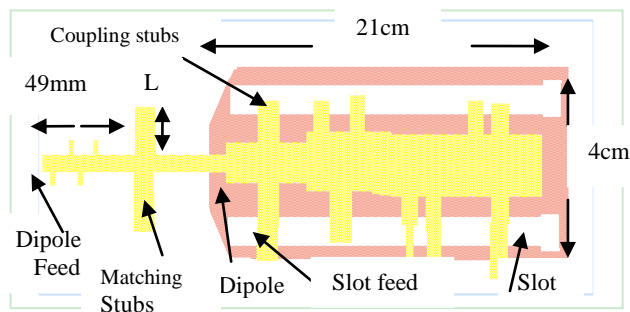FIG. 4: ANTENNA RADIATION PATTERN

FIG. 1 PRINTED DUAL POLARIZED ANTENNA, 26X6X0.16 CM
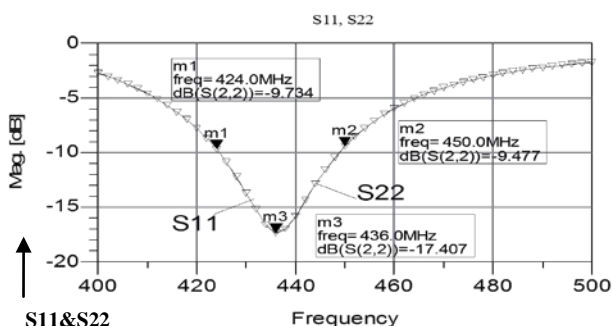

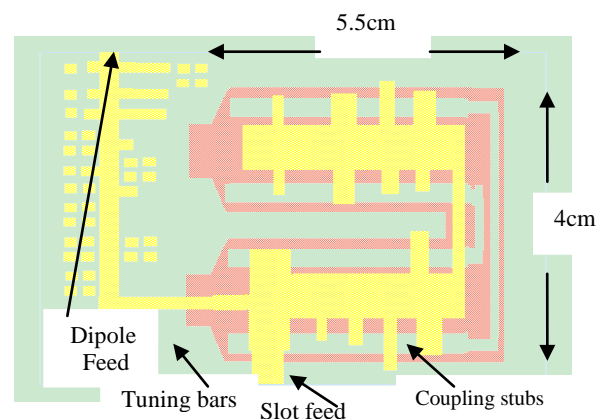FIG. 2 COMPUTED S11 AND S22 RESULTS

FIG. 5: FOLDED DUAL POLARIZED ANTENNA, 7X5X0.16CM

S11 and S12 parameters were measured directly on human body by using a network analyzer. In all measurements the measured results were compared to a known reference antenna.

New Loop Antenna with Ground Pane

A new loop antenna with ground plane has been designed on Kapton substrates with thickness of 0.25mm and 0.4mm. The antenna without ground plane is shown in Fig. 8.The loop antenna VSWR without the tuning capacitor was 4:1.This loop antenna may be tuned by adding a capacitor or varactor as shown in Fig. 8.
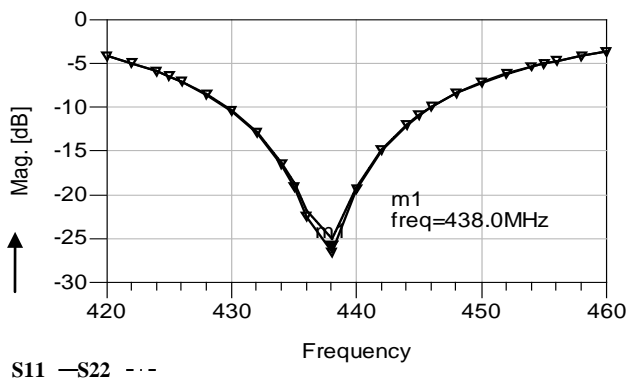
S11 ⎯S22 ·-·-

FIG. 6 FOLDED ANTENNA COMPUTED S11AND S22 RESULTS

This loop antenna may be tuned by adding a capacitor or varactor as shown in Fig. 8. Matching stubs are employed to tune the antenna to the resonant frequency. Tuning the antenna allows us to work in a wider bandwidth. Fig. 9 presents the loop antenna computed S11on human body. There is good agreement between measured and computed S11. The computed radiation pattern is shown in Fig 10. Table 1compares the electrical performance of a loop antenna with ground plane with a loop antenna without ground plane. There is a good agreement between measured and computed results of antenna parameters on human body. The results presented in Table 1 indicate that the loop antenna with ground plane is matched to the human body, without the tuning capacitor, better than the loop antenna without ground plane. The computed 3D radiation pattern is shown in Fig 11.The computed 3D radiation pattern and the coordinate used in this paper are shown in Fig 11. Computed S11 of the Loop Antenna with a tuning capacitor is given in Fig. 12.For frequencies ranging from 415MHz to 445MHz, the antenna has V.S.W.R better than 2:1 when there is no air spacing between the antenna and the patient body.

TABLE1 COMPARISON OF LOOP ANTENNAS

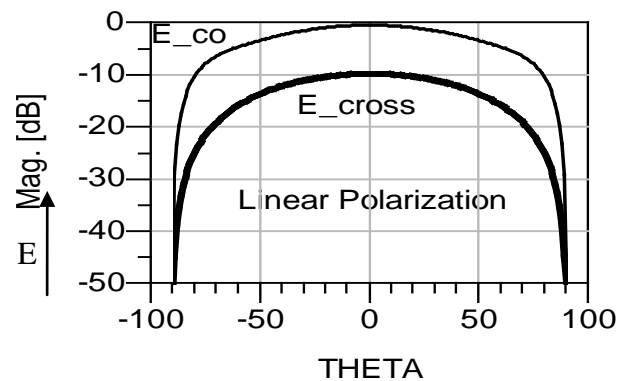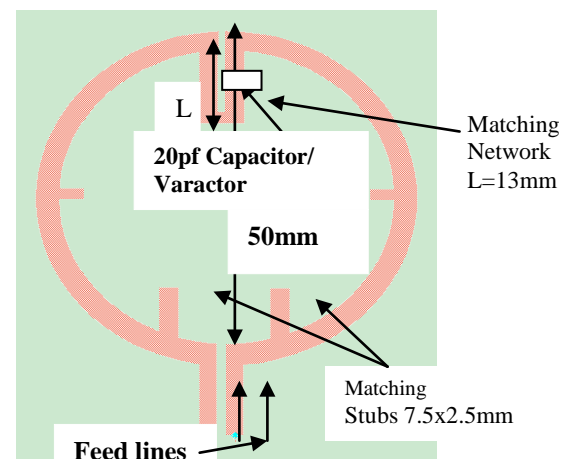| Antenna with no tuning capacitor	Beam width 3dB	Gain dBi	VSWR
Loop no GND	100°	0	4:1
Loop with GND	100°	0	2:1

FIG. 7 FOLDED ANTENNA RADIATION PATTERN

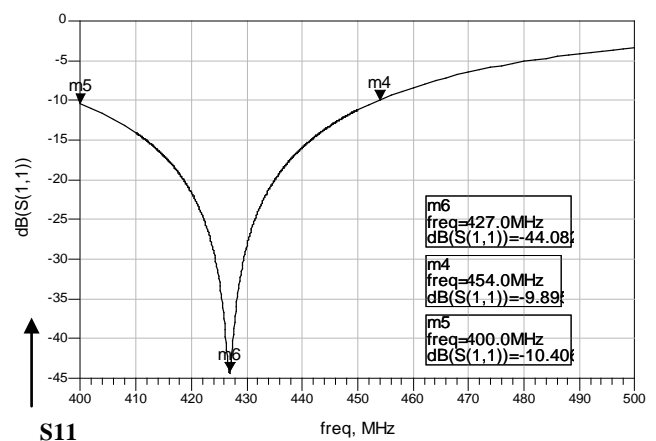FIG. 8: LOOP ANTENNA WITHOUT GROUND PLANE

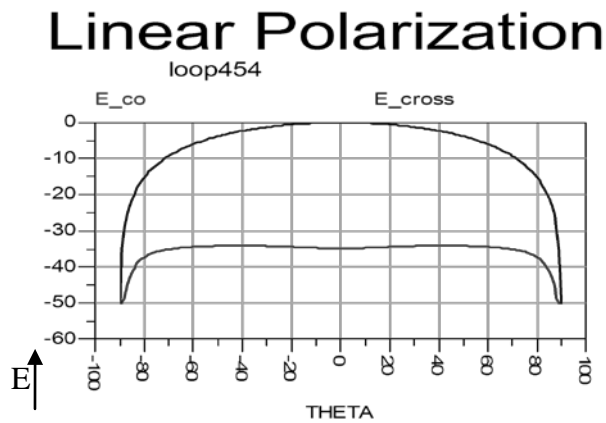FIG. 9: COMPUTED S11 OF NEW LOOP ANTENNA
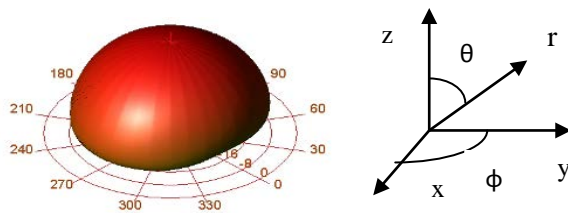
FIG. 10 NEW LOOP ANTENNA RADIATION PATTERN

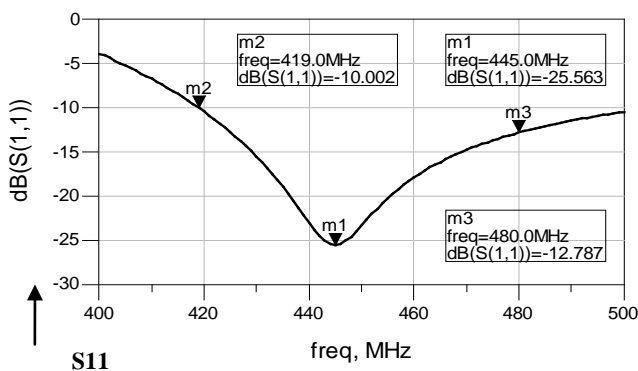FIG. 11 NEW LOOP ANTENNA 3D RADIATION PATTERN ON HUMAN BODY

FIG. 12 COMPUTED S11 OF LOOP ANTENNA, WITHOUT GROUND PLANE, WITH A TUNING CAPACITOR

Antenna S11 Variationas Functionof the Distancefrom Human Body

The Antennas input impedance variation as function of distance from the body had been computed by employing ADS software. The analyzed structure is presented in Fig. 14. The thickness of patient body has been varied from 15mm to 300mm. The location of the antenna on human body may be taken into account by calculating S11for different dielectric constant of the body. The variation of the dielectric constant of the body from 40 to 60 shifts the antenna resonant frequency up to 2%. The antenna was placed inside a belt with thickness between 2 to 4mm with dielectric constant from 2 to 4. The air layer between the belt and the patient shirt may vary from, 0mm to 8mm. The shirt thickness has been varied from 0.5mm to 1mm. The dielectric constant of the shirt has been varied from2 to 4. Properties of human body tissues, presented by Werber D., are listed in Table 2. These properties were employed in the antenna design.

TABLE 2 PROPERTIES OF HUMAN BODY TISSUES

Tissue	Property	434 MHz	600 MHz
Skin	σ	0.57	0.6
	ε	41.6	40.43
Stomach	σ	0.67	0.73
	ε	42.9	41.41
Colon, Muscle	σ	0.98	1.06
	ε	63.6	61.9
Lung	σ	0.27	0.27
	ε	38.4	38.4

Fig. 15 presents S11 results (of the antenna shown in Fig. 1) for different belt thickness, shirt thickness and air spacing between the antennas and human body. One may conclude from results shown in Fig. 15 that the antenna has V.S.W.R better than 2.5:1 for air spacing up to 8mm between the antennas and the human body. Results shown in Fig. 15 indicates that the antenna has V.S.W.R better than 2.0:1 for air spacing up to 5mm between the antennas and patient body. Fig. 16 presents S11 results for different position relative to the human body of the folded antenna shown in Fig. 5. Explanation of Fig. 16 is given in Table 3. If the air spacing between the sensors and the human body is increased, from 0mm to 5mm, the antenna resonant frequency is shifted by 5%. The antenna shown in Fig. 8 has V.S.W.R better than 2.0:1 for air spacing up to 5mm between the antennas and patient body.If the air spacing between the sensors and the human body is increased from 0mm to 5mm, the computed antenna resonant frequency is shifted by 2%. However, if the air spacing between the sensors and the human body is increased up to 5mm, the measured loop antenna resonant frequency is shifted by 5%. Explanation of Fig. 17 is given in Table 4. A voltage controlled varactor may be used to control the wearable antenna resonant frequencyat different locations on the human body as presented by Sabban A. in 2012.

Wearable Antennas

An application of the proposed antenna is shown in Fig. 18.Three to four folded dipole or loop antennas

may be assembled in a belt and attached to the patient stomach.

The cable from each antenna is connected to a recorder. The received signal is routed to a switching matrix. The signal with the highest level is selected during the medical test.The antennas receive a signal that is transmitted from various positions in the human body. Folded antennas may be also attached on the patient back in order to improve the level of the received signal from different locations in the human body. Fig. 19shows various antenna locations on the back and front of the human body for different medical applications.

FIG. 13 RADIATION PATTERN OF LOOP ANTENNA (WITHOUT GROUND) ON HUMAN BODY
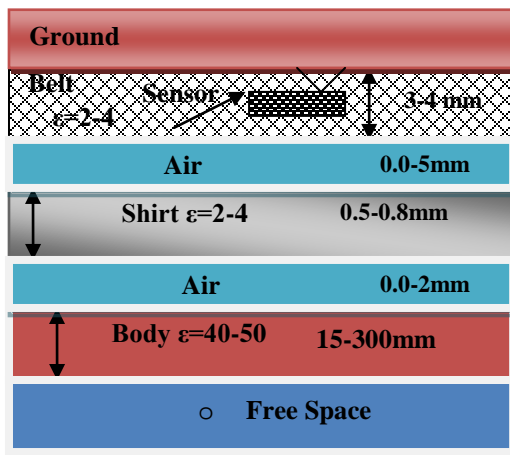

FIG. 14 ANALYZED STRUCTURE FOR IMPEDANCE COMPUTATIONS

In several applications,the distance separating the transmitting and receiving antennas is less than $2D^2/\lambda$.

D is thelargest dimension of the radiator. In theseapplications, the amplitude of the electromagnetic field close to the antenna may be quite powerful, but because of rapid fall-off with distance, the antenna do not radiate energy to infinite distances, but instead the radiated power remains trapped in the

region near to the antenna. Thus, the near-fields only transfer energy to close distances from the receivers.
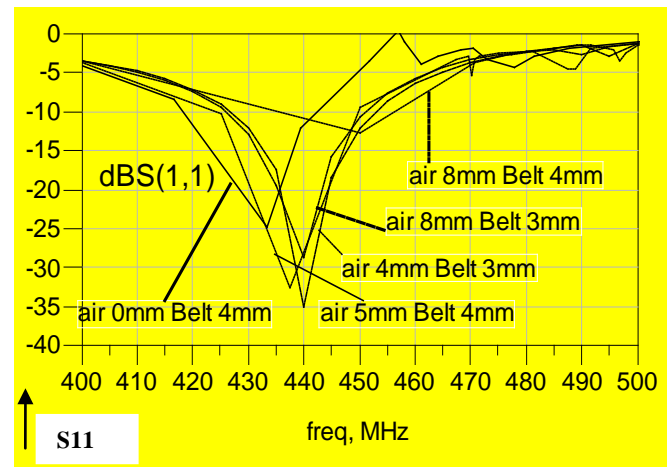

FIG. 15 THE S11 OF THE ANTENNA WITH DIFFERENT THICKNESSES AND SPACING RELATIVE TO THE HUMAN BODY

Thereceiving and transmitting antennas are magnetically coupled. Change in current flow through one wire induces a voltage across the ends of the other wire through electromagnetic induction. Theamount of inductive coupling between two conductors is measured by their mutual inductance. In these applications, we have to refer to the near field rather thanthe far field radiation. In Fig. 20 and 21,several microstrip antennas for medical applications at 434MHz are shown. The diameter of the loop antenna presented in Fig. 21 is 50mm. The dimensions of the folded dipole antenna are 7x6x0.16cm. The dimensions of the compact folded dipole presented in Fig. 21 are 5x5x0.5cm.
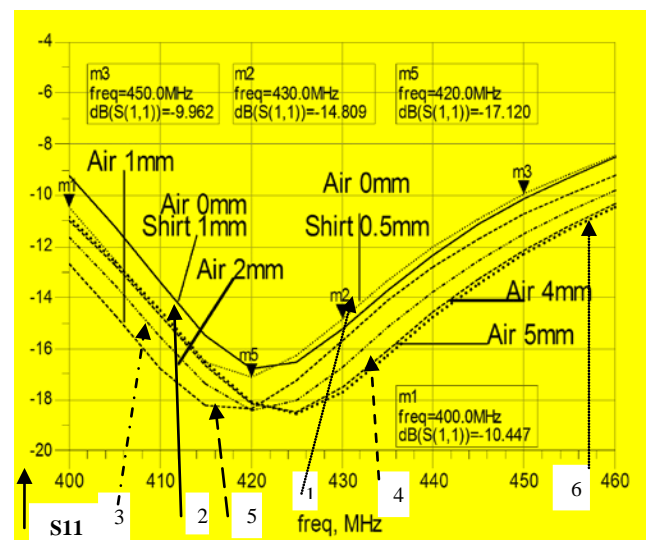

FIG. 16: FOLDED ANTENNA S11 RESULTS FOR DIFFERENT ANTENNA POSITION RELATIVE TO THE HUMAN BODY

TABLE 3 EXPLANATION OF FIG. 16

Picture #	Line type	Sensor position
1	Dot	Shirt thickness 0.5mm
2	Line	Shirt thickness 1mm
3	Dash dot	Air spacing 2mm
4	Dash	Air spacing 4mm
5	Long dash	Air spacing 1mm
6	Big dots	Air spacing 5mm

Compact Dual Polarized PrintedAntenna

A new compact microstrip loaded dipole antennas has been designed. The antenna consists of two layers of which the first layer is FR4 0.25mm dielectric substrate and thesecond layer isKapton 0.25mm substrate. The substrate thickness determines the antenna bandwidth. However, with thinner substrate we may achieve better flexibility. The proposed antenna is dual polarized.
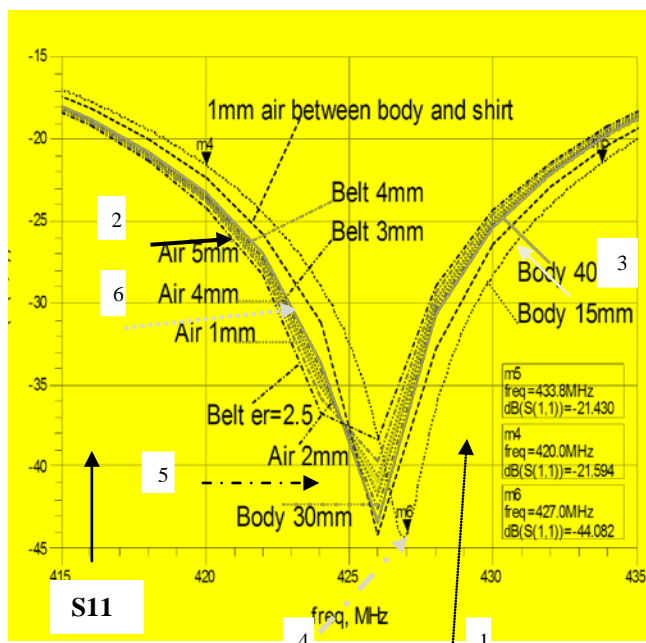

FIG. 17 LOOPS ANTENNA S11 RESULTS FOR DIFFERENT ANTENNA POSITION RELATIVE TO THE HUMAN BODY

TABLE 4 EXPLANATION OF FIG. 17

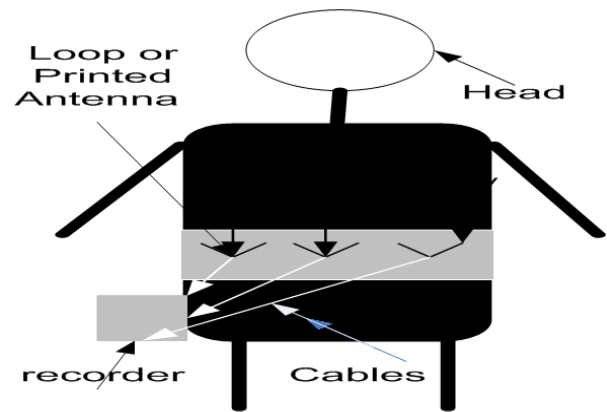| Picture #	Line type	Sensor position
1	Dot	Body 15mm air spacing 0mm
2	Line	Air spacing 5mm Body 15mm
3	Line	Body 40mm air spacing 0mm
4	Dash dot	Body 30mm air spacing 0mm
5	Dash dot	Body 15mm Air spacing 2mm
6	Dot	Body 15mm Air spacing 4mm

FIG. 18 PRINTED WEARABLE ANTENNA

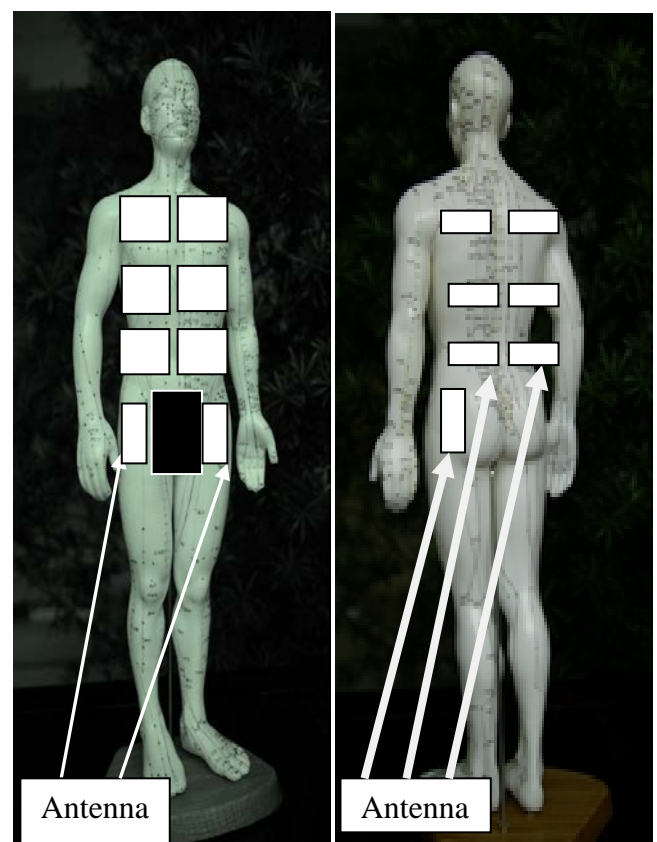The printed dipole and the slot antenna provide dual orthogonal polarizations.

FIG. 19 PRINTED PATCH ANTENNA LOCATIONS FORVARIOUS MEDICAL APPLICATIONS

The dual polarized antenna is shown in Fig. 22. The length and width of the coupling stubs in Fig. 22 are 10mm by 5mm. Small tuning bars are located along the feed line to tune the antenna to the desired resonant frequency. The antenna dimensions are 5x5x0.05cm. The antenna may be attached to the patient shirt in the patient stomach or back zone.

The computed 3D radiation pattern of the antenna is shown in Fig. 25. The computed radiation pattern is shown in Fig. 26.
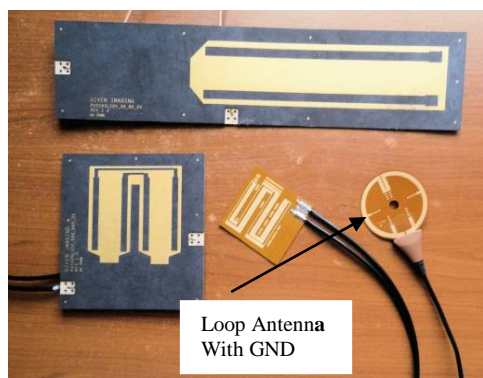
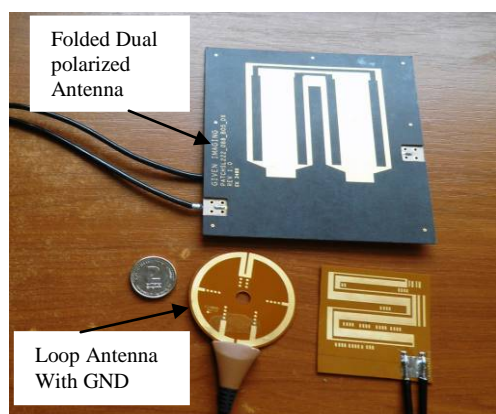FIG. 20 MICROSTRIP ANTENNAS FOR MEDICAL APPLICATIONS

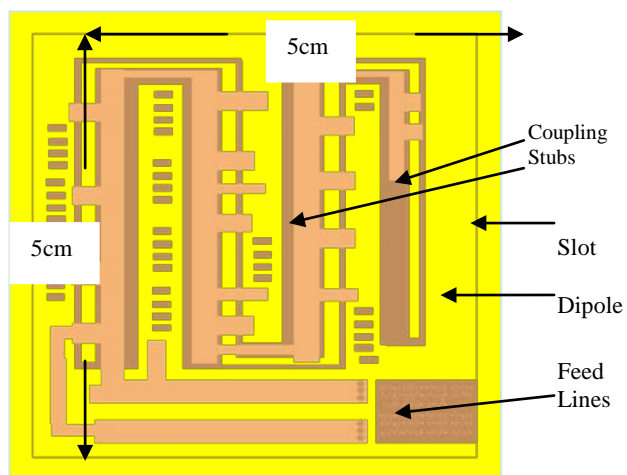FIG. 21: MICROSTRIP ANTENNAS FOR MEDICAL APPLICATIONS

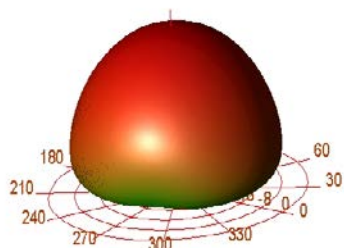

FIG. 22 PRINTED COMPACT DUAL POLARIZED ANTENNA
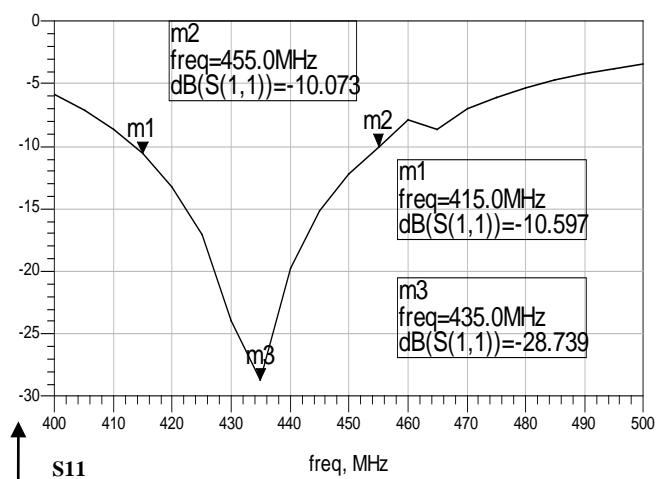

FIG. 25 3D ANTENNA RADIATION PATTERN

FIG. 23 COMPUTED S11 RESULTS OF THE COMPACT ANTENNA

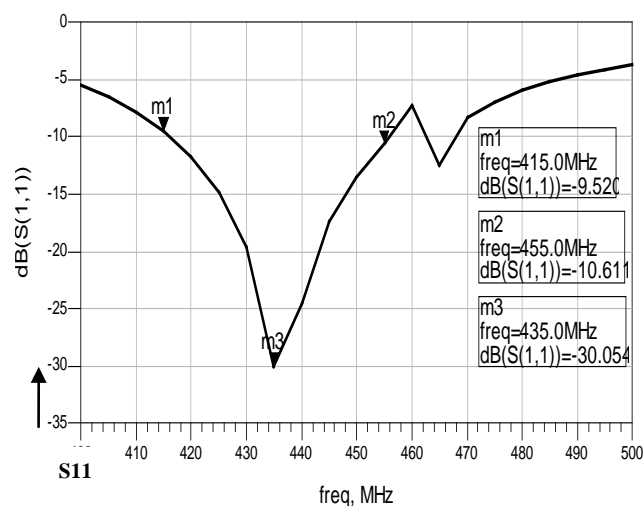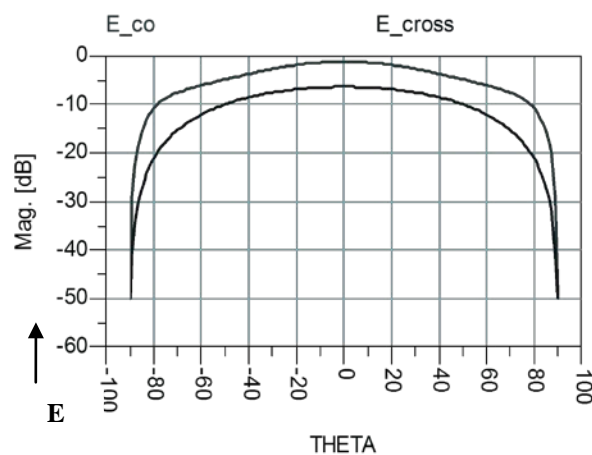FIG. 24 MEASURED S11 ON HUMAN BODY

FIG. 26: ANTENNA RADIATION PATTERN

Tuneable WearableAntennas

A voltage controlled varactor may be used to control the antenna resonant frequency. Varactors are connected to the antenna feed lines as shown in Figure 27.The antenna may be attached to the patient shirt in the patient stomach or back zone. The antenna has been analysed by using Agilent ADS software. There is a good agreement between measured and computed results.Fig. 28 presents the antenna S11 parameters as function of different varactor capacitances.The antenna resonant frequency varies around 5% for capacitances up to 2.5pF.
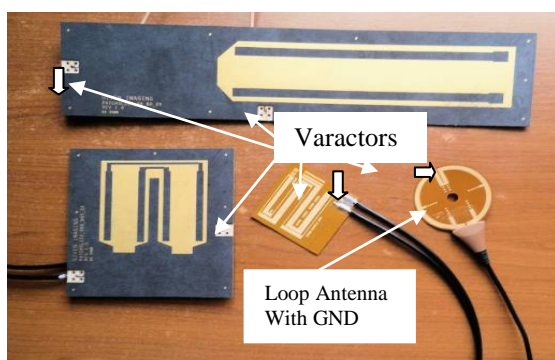

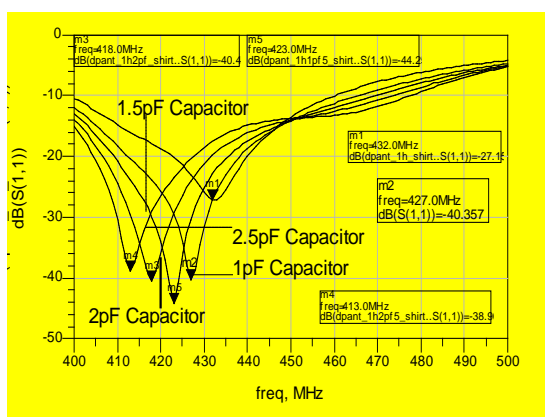FIG. 27 TUNEABLE ANTENNAS FOR MEDICAL APPLICATIONS

FIG. 28 S11 PARAMETER AS FUNCTION OF VARACTOR CAPACITANCE

The antenna bandwidth is around 10% for VSWR better than 2:1. The antenna beam width is around 100º. The antenna gain is around 2dBi. Fig. 29 presents a compact tuneable antenna with a varactor. Fig. 30 presents measuredS_{11} as function of varactor bias voltage. We may conclude that varactors may be used to compensate variations in the antenna resonant frequency at different locations on the human body.

13.5 MHz Wearable Antennas

One of the most critical elements of any RFID system is the electrical performance of its antenna. Compact printed antennas are crucial in the development of RIFD systems. A new compact microstrip loaded dipole antennas has been designed at 13.5MHz to provide horizontal polarization. The antenna consists of two layers of which the first layer is FR4 0.8mm dielectric substrate and thesecond layer isKapton 0.8mm substrate.

A printed slot antenna provides a vertical polarization. The proposed antenna is dual polarized.

FIG. 29 TUNEABLE ANTENNA WITH A VARACTOR

FIGURE 30 MEASURED S_{11} AS FUNCTION OF VARACTOR BIAS VOLTAGE

The printed dipole and the slot antenna provide dual orthogonal polarizations. The dual polarized antenna is shown in Fig. 31. The antenna dimensions are 6.4x6.4x0.16cm. The antenna may be attached to the customer shirt in the customer stomach or back zone. The antenna has been analyzed by using Agilent ADS software. The antenna S11parameter is better than -21dB at 13.5MHz. The antenna gain is around -10dBi.

The antenna beam width is around 160º. The computed S11 parameters are presented in Fig. 32. The antenna cross-polarized field strength may be adjusted by varying the slot feed location. The computed radiation pattern is shown in Fig. 33. Several designs with different feed network have been developed.The antenna input impedance variation as function of distance from the body has been computed by using ADS software.
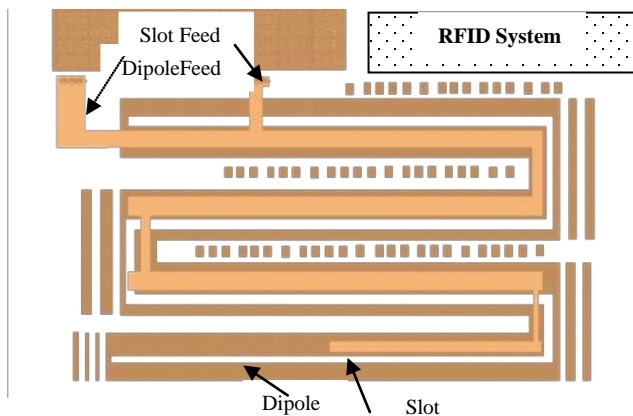

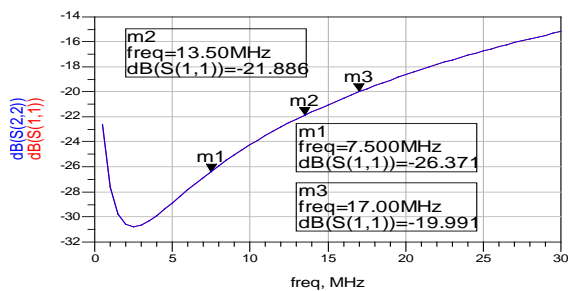FIG. 31 PRINTED COMPACT DUAL POLARIZED ANTENNA, 64X64MM
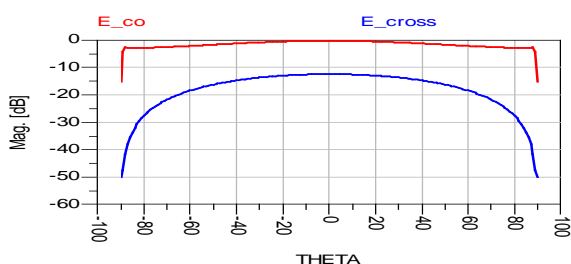

FIG. 32: COMPUTED S11 RESULTS

FIG. 33 ANTENNA RADIATION PATTERN

The analysed structure is presented in Fig. 14.

S11 parameters for different human bodythicknesses have been computed. Differences in S11 results for body thicknessof 15mm to 100mm are negligible. If the air spacing between the antenna and the human body is increased from 0mm to 10mm, the antenna S11

parameters may change by less than 1%. The VSWR was better than 1.5:1.

Conclusions

The interaction between printed antennas and human body is presented in this paper, along with the antenna S11 results for different shirt thickness, belt thickness and air spacing between the antennas and human body.The effect of the antenna location on the human body should be considered in the antenna design process.

This paper presents wideband microstrip antennas with high efficiency for medical applications. The antenna dimensions may vary from 26x6x0.16cm to 5x5x0.05cm according to the medical system specification. The antennas bandwidth is around 10% for VSWR better than 2:1. The antenna beam width is around 100º. The antennas gain varies from 0 to 2dBi. The antenna S11 results for different belt thickness, shirt thickness and air spacing between the antennas and human body have been presented in this paper. If the air spacing between the new dual polarized antenna and the human body is increased from 0mm to 5mm, the antenna resonant frequency is shifted by 5%. The proposed antenna may be used in Medicare RF systems.Varactors may be used to compensate variations in the antenna resonant frequency at different locations on the human body. A novel 13.5MHz wearable printed antenna has been presented in this paper.The antenna beam width is around 160º. The antenna gain is around -10dBi.

REFERENCES

AlomainyA., A. Sani et all "Transient Characteristics of Wearable Antennas and Radio Propagation Channels for Ultrawideband B ody-centric Wireless Communication", I.E.E.E Trans. on Antennas and Propagation, Vol. 57, No. 4, April 2009, pp. 875-884.

Gupta, B., Sankaralingam S., Dhar, S.,"Development of wearable and implantable antennas in the last decade", Microwave Symposium (MMS), 2010 Mediterranean 2010 , Page(s): 251 – 267.

IzdebskiP. M., H. Rajagoplan and Y. Rahmat-Sami, " Conformal Ingestible Capsule Antenna: A Novel Chandelier Meandered Design",", I.E.E.E Trans. on Antennas and Propagation, Vol. 57, No. 4, April 2009, pp. 900-909.

JamesJ.R., P.S Hall and C. Wood, "Microstrip Antenna Theory and Design",1981.

KastnerR., E. Heyman, A. Sabban, "Spectral Domain Iterative Analysis of Single and Double-Layered Microstrip Antennas Using the Conjugate Gradient Algorithm", I.E.E.E Trans. on Antennas and Propagation, Vol. 36, No. 9, Sept. 1988, pp. 1204-1212.

Kellomaki T., Heikkinen J., Kivikoski, M., "Wearable antennas for FM reception", First European Conference on Antennas and Propagation, EuCAP 2006 , pp. 1-6.

KlemmM. and G. Troester, "Textile UWB antenna for Wireless Body Area Networks", ", I.E.E.E Trans. on Antennas and Propagation, Vol. 54, No. 11, Nov. 2006, pp. 3192-3197.

Lawrence C. Chirwa*, Paul A. Hammond, Scott Roy, and David R. S. Cumming, "Electromagnetic Radiation from Ingested Sources in the Human Intestine between 150 MHz and 1.2 GHz", IEEE Transaction on Biomedical eng., VOL. 50, NO. 4, April 2003, pp 484-492.

SabbanA. and K.C. Gupta, "Characterization of Radiation Loss from Microstrip Discontinuities Using a Multiport Network Modeling Approach", I.E.E.E Trans. on M.T.T, Vol. 39,No. 4,April 1991, pp. 705-712.

SabbanA.," A New Wideband Stacked Microstrip Antenna", I.E.E.E Antenna and Propagation Symp., Houston, Texas, U.S.A, June 1983.

SabbanA., E. Navon " A MM-Waves Microstrip Antenna Array", I.E.E.E Symposium, Tel-Aviv, March 1983.

SabbanA., "Wideband Microstrip Antenna Arrays", I.E.E.E Antenna and Propagation Symposium MELCOM, Tel-Aviv,1981.

SabbanA., "Microstrip Antenna Arrays", Microstrip Antennas, Nasimuddin Nasimuddin (Ed.), ISBN: 978-953-307-247-0, InTech,

http://www.intechopen.com/articles/show/title/microstrip

-antenna-arrays , pp..361-384, 2011.

SabbanA., "Wideband printed antennas for medical applications" APMC 2009 Conference, Singapore, 12/2009.

SabbanA., "Wideband Tunable Printed Antennas for Medical Applications", I.E.E.E Antenna and Propagation Symp., Chicago IL. , U.S.A, July 2012.

Salonen, P., Rahmat-Samii, Y., Kivikoski, M.," Wearable antennas in the vicinity of human body", IEEE Antennas and Propagation Society International Symposium, 2004. Vol.1 pp. 467 – 470.

Thalmann T., Popovic Z., Notaros B.M, Mosig, J.R.," Investigation and design of a multi-band wearable antenna", 3rd European Conference on Antennas and Propagation, EuCAP 2009. Pp. 462 – 465.

WerberD., A. Schwentner, E. M. Biebl, "Investigation of RF transmission properties of human tissues", Adv. Radio Sci., 4, 357–360, 2006.

A. Sabban (M'87-SM'94) received the B.Sc and M.Sc degrees with excelencein electrical engineering from Tel Aviv University, Israel, in 1976 and 1986 respectively.

He received the Ph.D. degree in electrical engineering from Colorado University at Boulder, USA, in 1991.

Dr. A. Sabban reasearch interests are microwave and antenna engineering. He published over 60 research papers and hold a patent on wideband microstrip antennas.

In 1976 he joined the armament development authority RAFAEL in Israel. In RAFAEL he worked as a senior researcher, group leader and project leader in the electromagnetic department till 2007. In 2007 he retired from RAFAEL. From 2008 to 2010 he worked as an RF Specialist and project leader in Hitech companies. Since 2010 to date he is a senior lecturer and researcher in Ort Braude College in Israel in the electrical engineering department.